Available online at www.sciencedirect.com
SCIENCE DIRECT®

ELSEVIER

Food Control 14 (2003) 255–261

FOOD CONTROL

www.elsevier.com/locate/foodcont

Storage and drying of grain in Canada: low cost approaches

Digvir S. Jayas *, Noel D.G. White [1]

Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB, Canada R3T 5V6

Received 11 November 2001; received in revised form 7 January 2003; accepted 9 January 2003

Abstract

Most Canadian grain (>70% of harvests) is stored on the farm. High moisture content of grain at harvest rapidly leads to spoilage and occasionally the production of the mycotoxins sterigmatocystin, ochratoxin A, or citrinin. Near ambient drying systems that consist of an electrical fan at the base of a granary blowing air into a plenum beneath a perforated floor under stored grain is relatively economical. Heat produced by the fan can dry grain by 2% moisture content in 2 months at a cost for electricity of Can. $0.87/tonne. Hot air dryers are used on wet grain at harvest to rapidly lower 21% moisture content maize to 15% moisture content at a cost of Can. $7.80/tonne for propane plus aeration costs to cool the grain. Procedures for safe storage of grain are outlined and the capabilities and planned use of a new grain storage research facility at the University of Manitoba are discussed.

Keywords: Grain storage; Near-ambient drying; Hot air drying; Aeration systems; Insects

1. Introduction

On average, 2.0 Bt (billion tonnes) of grains, oilseeds, and legumes (hereafter referred to as grains) are produced annually in the world (Statistical handbook, 2000). The grains need to be stored safely until consumed. A stored grain bulk is a man-made ecological system in which deterioration of the stored product results from interactions among physical, chemical, and biological factors. The important factors are: temperature, moisture, carbon dioxide (CO_2), oxygen (O_2), grain characteristics, microorganisms, insects, mites, rodents, birds, geographical location, and granary structure (Jayas, 1995). The storage life of grains depends mainly on two physical factors: temperature and moisture content (Fig. 1). The survival and reproduction of biological agents in grain are dependent to a great extent on the temperature and moisture levels (White, 1995). Stored-product insects can live at temperatures from 8 to 41 °C and inter-granular relative humidities (r.h.) from 1% to 99% (Sinha & Watters, 1985). Usually development and multiplication are optimum near 30 °C and 50–70% r.h. (Howe, 1965; Sinha, 1973a; Sinha & Watters, 1985) but stop at 18 °C (Fields & White, 1997). Mites can live at temperatures from 3 to 41 °C and relative humidities from 42% to 99% with the optimum for development and multiplication near 25 °C and 70–90% r.h. Fungi can develop at temperatures from −2 to 55 °C and relative humidities from 70% to 90% with the optimum temperature near 30 °C, and relative humidity around 80%. There is considerable variation in optimum conditions for different species. Localized regions may occur in stored-grain bulks for optimum development and multiplication of insects, mites, and fungi even when the average conditions of the bulk would prevent pest infestation.

Mycotoxins are poisonous metabolites produced by certain fungal genera, which can infect crops both in the field and in storage. Toxins produced by storage fungi in grain in Canada are sterigmatocystin, ochratoxin A, and citrinin. Several toxins are produced pre-harvest by *Fusarium* fungi (D. Abramson, personal communication). Conditions favoring the development of mycotoxins in cereals before and after harvest are not well-understood, but are of particular importance to grain-exporting countries concerned with maintaining high standards of quality in their produce. On-farm storage is common in the Canadian prairie region, and granary studies have shown the potential for mycotoxin formation in several stored cereal grains when they have high moisture contents (Abramson, Sinha, & Mills, 1980,

* Corresponding author. Tel.: +1-204-474-6860; fax: +1-204-474-7568.
E-mail address: digvir_jayas@umanitoba.ca (D.S. Jayas).
[1] Address: Cereal Research Centre, Agriculture and Agri-Food Canada, 195 Dafoe Road, Winnipeg, MB, Canada R3T 2M9.

0956-7135/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0956-7135(03)00014-8

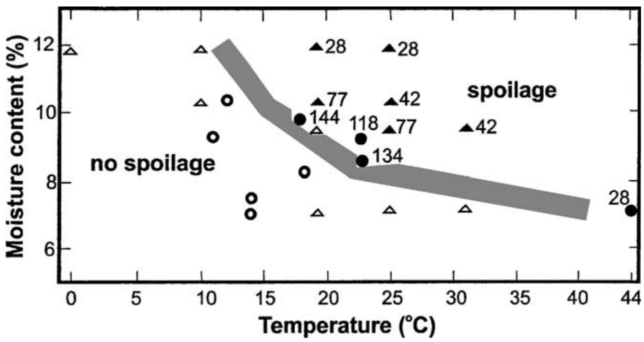

Fig. 1. Safe storage guidelines for canola (MDA, 1987).

1983, 1985, 1990a,b, 1999). Although many cause–effect relationships have yet to be investigated, some factors likely to affect mycotoxin formation are: moisture, temperature, time, invertebrate vectors, damage to the seed, O_2 and CO_2 levels, inoculum load, composition of substrate, fungal infection level, prevalence of toxigenic strains, and microbiological interactions (Abramson et al., 1999). It has been postulated that crop spoilage, fungal growth and mycotoxin formation result from the interaction of several of these factors in stored products (Abramson, 1991; Frisvad, 1995; Ominski, Marquardt, Sinha, & Abramson, 1994; Wilson & Abramson, 1992). An understanding of the factors involved would facilitate the prediction and prevention of mycotoxin development.

Deterioration of grain and production of mycotoxins in grains can be reduced by properly drying grain to or below safe moisture contents (Table 1) and storing it at cool temperatures in properly designed storage structures (Jayas, White, & Muir, 1995). Mathematical models can be used to predict abiotic parameters such as moisture content, inter-granular CO_2 and grain temperature which can be correlated to changes in levels of biotic agents and mycotoxin production. This paper describes the structures commonly used for storage of grains in Canada, procedures needed to maintain the quality of grains and the role of mathematical models in managing stored-grain ecosystems.

Table 1
Upper limit of safe moisture contents[a] for storing grain up to a year under Canadian Prairie climatic conditions

Crop	Moisture content[b] (% wb)
Wheat	14.5
Oats	14.0
Barley	14.8
Rye	14.0
Flaxseed	10.0
Canola and rapeseed	10.0
Mustard seed	9.5
Peas	16.0
Lentils	14.0
Fababeans	16.0
Buckwheat	16.0
Triticale	14.0
Corn	15.5
Soybeans	14.0
Sunflower seed	9.5
Safflower seed	9.5

[a] Compiled from CGC (1993).
[b] For long-term storage (>1 year) in well-engineered structures, the moisture content should be 1–3% points less than the values listed in this table. Depending on the climatic conditions of a region, values given in Table 1 may need to be changed considerably.

2. Canadian system

2.1. Brief description

Canada produces an average of 55 Mt (million tonnes) of grains annually (Statistical handbook, 2000). About 70% of these grains are exported through a well-planned grain distribution system. Typically the producers store their grain on-farm in flat-bottom bins of about 100 tonne capacity. These cylindrical bins are made by bolting sections of corrugated steel together (Fig. 2). Although hopper-bottom bins cost more than flat-bottom bins per tonne of storage, many farmers are buying welded-steel hopper-bottom bins (Fig. 3) to store their grain. The main reasons for the purchase of hopper-bottom bins by the farmers are: (i) the ease of grain handling, (ii) less exposure to grain dust during unloading because no shoveling of grain is required, and (iii) perceived less spoilage in the hopper-bottom bin. Westeel (a Division of Jannock Steel Fabricating Company), a major flat-bin manufacturer in Manitoba, has started manufacturing a hopper-bottom for retrofitting to corrugated-steel flat-bottom bins.

Farmers deliver their grain to primary elevators (grain handling facilities) using farm trucks. The grain is graded by visual inspection or comparison with standard samples or both. The standard samples are prepared every year by the Canadian Grain Commission to

Fig. 2. Corrugated steel, flat-bottom bins at Cereal Research Centre Farm (28 tonne capacity).

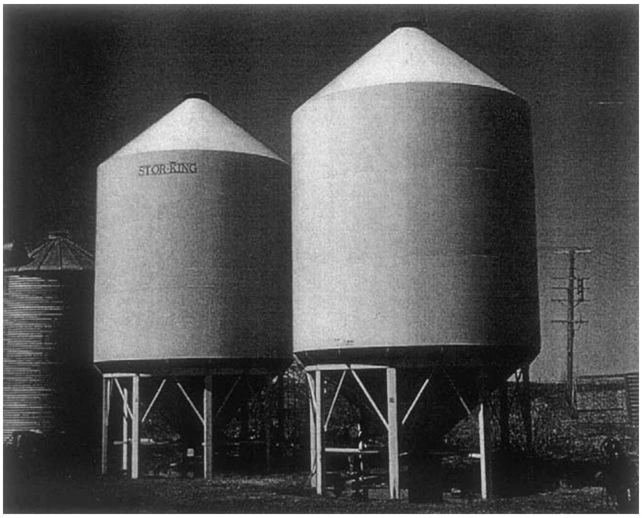

Fig. 3. Welded-steel hopper-bottom bins at Glenlea Research Farm (56 tonne capacity).

reflect the environmental conditions during harvest. Railway cars transport the grain from primary elevators to terminal elevators (export elevators). The terminal elevators, clean, store and ship grain to export standards. When needed, grain is typically dried on farms.

2.2. Need for drying grains

It is not always possible to reduce the moisture content of grains to safe levels in the field because of many uncontrollable factors. In many countries, price of grains is high just before the harvest of new crops. By harvesting grains wet and removing moisture artificially, farmers or managers of cooperative farms (hereafter referred to as farmers) may increase their profits. In other parts of the world where two or three crops are grown in a year, harvesting grains at high moisture reduces the growing season (because the crop is not dried in the field) for each crop and thus provides farmers more time for other in-field operations. Harvesting of "wet" grains increases the harvest period allowing a longer use of harvesters on mechanized farms or of scarce manual labor used for harvesting in many parts of the world. Harvesting of "wet" grains reduces shattering losses in the field. In many years, frequent rains force farmers to harvest "wet" grains. Therefore, artificial removal of moisture from grains is a necessity on all farms (Pabis, Jayas, & Cenkowski, 1998). Grain can be dried using air at near-ambient or high temperatures resulting in "near-ambient air" or "hot air" drying.

2.3. Near-ambient drying system—a relatively slow but low cost technology

In a typical near-ambient system, the main components of the drying system are: a bin to contain bulk grains, a plenum with a perforated area to introduce air through the grains, a fan to force air, and one or more roof vents to exhaust air (Fig. 4). Air is forced through the bulk at 5 to 40 (L/s)/m^3 of grain, depending on the moisture content, grain is dried in layers and distinct zones of dry, drying, and wet grain are created in the bulk (Fig. 4). The configuration of drying patterns and progress of drying depend on the type of grain being dried, initial moisture of the grain, condition and amount of air being forced through the grain, and the uniformity of air distribution within the grain bulk. A flat-bottom bin filled to a level surface and equipped with a fully perforated floor above a plenum provides the most uniform air distribution through bulk grain. Many other configurations and size of bins are used for this purpose. Other configurations of air plenums are shown in Fig. 5 for flat-bottom bins, and in Fig. 6 for hopper-bottom bins. In these systems (Figs. 5 and 6), the main direction of air movement through the grain is vertically up. Systems are also designed such that air travels mainly horizontally through grain (Fig. 7a) or vertically downward through grain (Fig. 7b). Other designs to introduce air into flat and hopper-bottom bins are continually being developed. Near-ambient drying can lower the moisture content of canola up to 2% over 2 months after harvest (September–November) at a cost of Can. \$0.87/tonne (the cost in 2002) (kilowatts of fan $\times$ hours $\times$ \$0.055 per kW h) (Sinha, Mills, Wallace, & Muir, 1981).

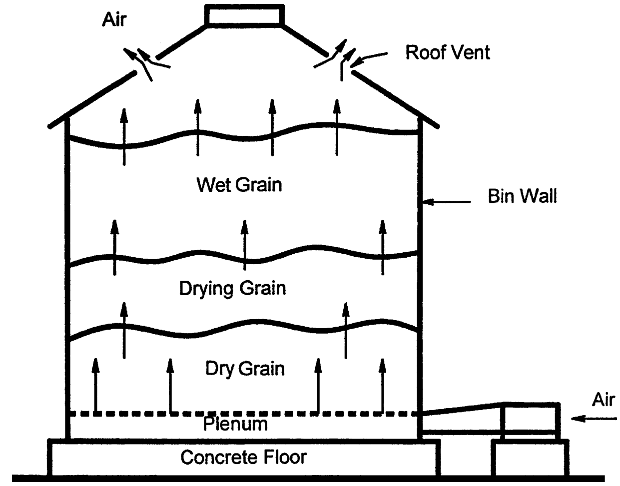

Fig. 4. Components of a near-ambient grain drying system and the movement of the drying front (Pabis et al., 1998).

2.4. Hot air dryers

Dryers used for grain drying can be classified based on: (i) flow of grain (batch, recirculating, and continuous); (ii) relative motions of grain and drying air (concurrent, counter-current, cross, and mixed flow); and

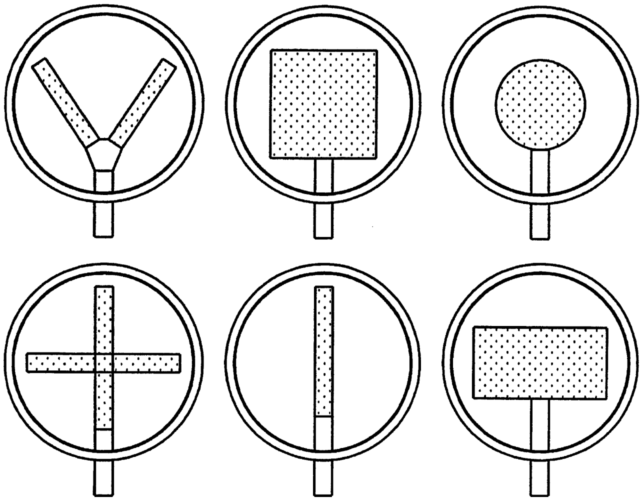

Fig. 5. Various configurations of partially perforated floors for introduction of near-ambient air for drying grain in flat-bottom bins (MDA, 1987).

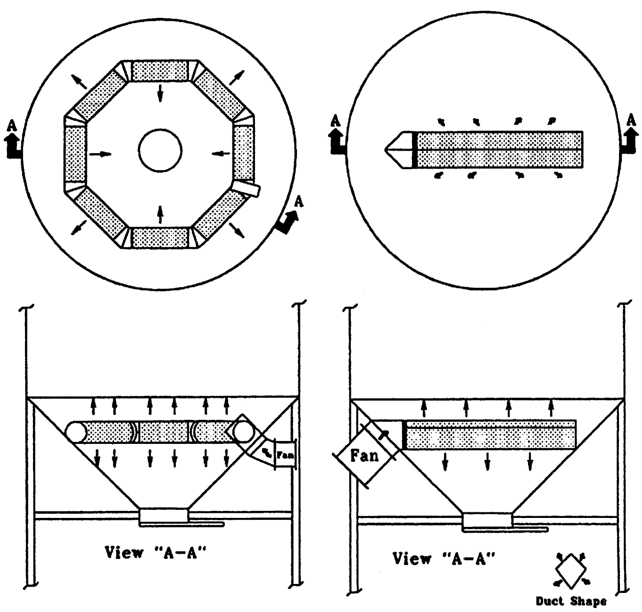

Fig. 6. An example of a system to introduce near-ambient air for drying grain in hopper-bottom bins (Pabis et al., 1998).

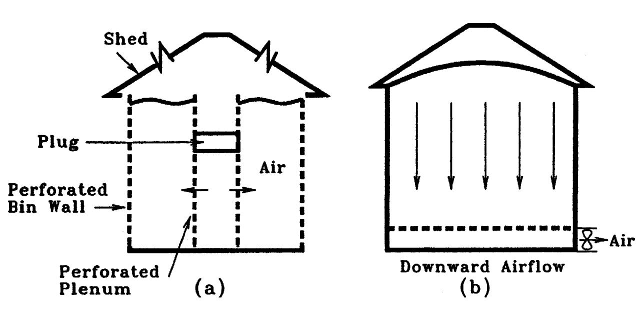

Fig. 7. Near-ambient drying systems with mainly horizontal (a) and vertically downward airflow (b) (Pabis et al., 1998).

Table 2
Maximum safe temperature (°C) of heated air entering grain for drying for various end uses (Hall, 1980)

Crop	End use		
	Seed	Commercial use[a]	Animal feed[a]
Ear corn	43	54	82
Shelled corn	43	54	82
Wheat	43	60	82
Oats	43	60	82
Barley	41	41	82
Sorghum	43	60	82
Soybeans	43	49	
Rice	43	43	
Peanuts	32	32	

[a] Higher air temperatures than those listed may be used when the grain is dried under carefully controlled conditions so that the maximum temperature of the kernels, at any time, does not exceed those listed in the table.

(iii) source of heat (solar, propane, and electrical). The relative motions of grain and drying air only occur in the continuous flow dryers. Either propane or electrical sources of heat can be used in all types of dryers. Therefore, various types of dryers used in the grain industry can be placed into three groups: batch, recirculating, and continuous (Pabis et al., 1998). When using hot air for drying grain, grain should not be heated above the maximum allowed temperature for a particular end use (Table 2). A typical example of the cost of drying maize from 21% to 15% using a propane batch drier is Can. $7.80/tonne (Personal communication, F. Helen, Oakbank, MB). The dried maize must then be rapidly cooled by aeration.

3. Procedures for safe storage of grains

Once grain is dry and cool and placed in a weatherproof and rodent-proof structure it can usually be stored for long periods without suffering quality loss from fungal deterioration or insect feeding such as lowered germination, increased free fatty acids and other biochemical changes (Tipples, 1995). However, if grain is stored in large bulks without aeration it will be indirectly affected by the weather. The bulk will retain the heat it had at harvest in the centre of the bulk (Jayas, Alagusundaram, Shunmugam, Muir, & White, 1994) and reflect external ambient temperatures near the periphery. In Canada, grain can remain warm (15–20 °C) throughout the winter (outside temperatures can be as low as −20 to −30 °C) and air convection currents carry moisture to the top-centre of the bulk which can result in localized grain spoilage (Jayas, 1995; Sinha, Yaciuk, & Muir, 1973) and mycotoxin production (Abramson, 1991).

Insects, mites, and fungi can rapidly increase in moist and warm grain producing heat, moisture, and CO_2 by respiration (White & Sinha, 1980). Specific climatic conditions determine which form of spoilage is most likely to occur (Sinha, 1973b) with mites predominating in temperate climates, fungi in tropical humid or subtropical humid climates and insects in dry, hot climates.

The practicality of aeration cannot be overstated because grain is often harvested hot [up to 8 °C warmer than ambient air temperature at harvest (Prasad, Muir, & Wallace, 1978)] and wet. In one Canadian study wheat and barley stored in 550-tonne capacity bins were monitored for each of 12 annual storage cycles (White et al., 1999). There were two 3-horse-power (2.25 kW) fans per bin with 5% of the floor area perforated steel with a corresponding air plenum. Grain was typically harvested near 34 °C but with continuous aeration was <20 °C within 2 weeks so insects and fungi were rarely a problem and fan operation varied from 221 h in one year to 678 h in the wettest year. In the wettest 2 years pockets of molding grain occurred near the floors and after 1 year of storage 0.7 ppm ochratoxin A occurred in wheat and 5.2 ppm citrinin, 2.2 ppm ochratoxin A, and traces of sterigmatocystin were found in the mouldy barley. The moulded grain was discarded.

Good storage practices have been outlined by White (2000) and include the following procedures:

- Prepare the bin, before storing the new crop: sweep or vacuum the floor and walls; burn or bury sweepings that contain spoiled or infested grain; seal cracks to keep out flying insects from outside, rain, and snow; and spray the walls and floors with a recommended insecticide.
- Install an aeration system to reduce temperature gradients and moisture condensation.
- Dry tough or damp crops soon after harvest as they are more likely to heat and become infested with insects and mites than dry (straight-grade) crops; then cool after drying.
- Examine stored crops every 2 weeks for signs of heating or infestation; either check temperatures, carbon dioxide levels, and insect activity by traps, or probe and screen samples.
- Move heated or infested crops into another bin if outdoor temperatures are sufficiently cold to break up hot-spots and control infestation.
- Check the top of binned crops and remove snow, if present, before a crust of mold develops.
- If an insect infestation occurs and aeration is not available, seal the bin and fumigate the grain with phosphine gas.

4. Role of mathematical models

Experimental studies can be conducted to measure changes in temperature, moisture content, and gas concentration in stored grain. But the large number of biotic and abiotic factors and their inter-relationships in stored-grain ecosystems makes full-scale experimental studies expensive and time consuming, and the generalizations needed to predict the variables accurately are difficult to make. Mathematical models, if based on the principles of physical and biological sciences and properly validated, can be used to study the effect of various parameters such as weather, grain condition, and size, shape, and material of the storage structure on the distribution of temperature, moisture, and gases (Jayas et al., 1994). The major advantages of validated models are their ability to answer "what if?" questions and their transferability to different climatic regions of the world. If economic and social considerations are suitable this transferability can make the models globally rather than locally applicable as is expected of experimental studies (Jayas, 1995).

5. Grain storage research facility

A facility has been built at the University of Manitoba to conduct research on all aspects of grain storage (Fig. 8). Examples of potential collaborative research projects between engineers in the Department of Biosystems Engineering at the University of Manitoba and scientists at the Cereal Research Centre of Agriculture and Agri-Food Canada are:

Fig. 8. Grain storage research facility at the University of Manitoba.

(a) to optimize computer control strategies for drying and aerating grains, oilseeds, and new crops as they become important, such as beans, lentils, and peas;
(b) to develop automatic controls for fans for near-ambient drying and aeration;
(c) to evaluate existing and design new systems to introduce air into the grain for drying and aeration in hopper-bottom bins;
(d) to determine air conditions and combinations of methods for drying new crops without detrimental effects on end-use quality;
(e) to design and evaluate new sensors and automatic controls for high temperature dryers;
(f) to design and develop new, economically feasible, drying systems (e.g., infrared and microwave drying);
(g) to design and evaluate cleaning equipment and material handling systems for specialty crops to ensure quality is preserved;
(h) to develop new cleaning and handling systems that minimize seed loss during cleaning and handling;
(i) to develop systems to automatically sample, analyze using machine vision technology, and adjust cleaning and handling machines to maximize cleaner throughput while meeting pre-established cleaning tolerances;
(j) to develop the potential of machine vision technology to assist grain inspectors in grain grading and in detecting insect infestations and fungal damage;
(k) to design systems to kill insects in grain using carbon dioxide;
(l) to design systems to kill insects using high temperatures without detrimental effects on grain quality;
(m) to develop aeration strategies to use Canadian cold ambient-temperatures for controlling insects;
(n) to develop integrated pest management (IPM) strategies;
(o) to develop new grain transport logistics (e.g., containerized shipping or compacted flour);
(p) to design and develop new equipment for dehulling pulses;
(q) to measure physical properties, sorption and desorption isotherms, and thermal properties of grain;
(r) to determine storability of new crops, crop products, new cultivars of established crops, and animal feeds;
(s) to develop processing technologies that uniformly mix medicinal and nutritional components into feed; and
(t) other projects of interest to the Canadian and world grain industry.

Acknowledgements

The funding to build the Grain Storage Research Facility were provided by the Canada Foundation for Innovation, Manitoba Innovation Fund, Western Economic Diversification, Manitoba Hydro, Agriculture and Agri-Food Canada, industry and private donors, and the University of Manitoba. Research funds are usually provided by Natural Sciences and Engineering Research Council of Canada, Canada Research Chair Program, industry, and Manitoba Government.

References

Abramson, D. (1991). Development of molds, mycotoxins and odors in moist cereals during storage. In J. Chelkowski (Ed.), *Cereal grain: Mycotoxins, fungi and quality in drying and storage* (pp. 119–147). Amsterdam: Elsevier.

Abramson, D., Mills, J. T., & Sinha, R. N. (1990a). Mycotoxin production in amber durum wheat stored at 15 and 19% moisture content. *Food Additives and Contaminants, 7*, 617–628.

Abramson, D., Sinha, R. N., & Mills, J. T. (1980). Mycotoxin and odor formation in moist cereal grain during granary storage. *Cereal Chemistry, 57*, 346–351.

Abramson, D., Sinha, R. N., & Mills, J. T. (1983). Mycotoxin and odor formation in barley stored at 16 and 20% moisture in Manitoba. *Cereal Chemistry, 60*, 350–355.

Abramson, D., Sinha, R. N., & Mills, J. T. (1985). Mycotoxin formation and quality changes in granary-stored corn at 16 and 21% moisture content. *Sciences des Aliments, 5*, 653–663.

Abramson, D., Sinha, R. N., & Mills, J. T. (1990b). Mycotoxin formation in HY-320 wheat during granary storage at 15 and 19% moisture content. *Mycopathologia, 111*, 181–189.

Abramson, D., Hulasare, R., White, N. D. G., Jayas, D. S., & Marquardt, R. R. (1999). Mycotoxin formation in hulless barley during granary storage at 15 and 19% moisture content. *Journal Stored Products Research, 35*, 297–305.

Anonymous, 2000. *Statistical handbook*. Winnipeg, MB: Canada Grains Council.

CGC (1993). Grain grading handbook for Western Canada. Winnipeg, MB: Canadian Grain Commission.

Hall, C. W. (1980). *Drying and storage of agricultural crops*. West port, CT: AVI.

Fields, P. G., & White, N. D. G. (1997). Survival and multiplication of stored-product beetles at simulated and actual winter temperatures. *Canadian Entomologist, 129*, 887–898.

Frisvad, J. C. (1995). Mycotoxins and mycotoxigenic fungi in storage. In D. S. Jayas, N. D. G. White, & W. E. Muir (Eds.), *Stored-grain ecosystems* (pp. 251–288). New York, NY: Marcel Dekker.

Howe, R. W. (1965). A summary of estimates of optimal and minimal conditions for population increase of some stored products insects. *Journal of Stored Products Research, 1*, 177–184.

Jayas, D. S. (1995). Mathematical modeling of heat, moisture, and gas transfer in stored-grain ecosystems. In D. S. Jayas, N. D. G. White, & W. E. Muir (Eds.), *Stored-grain ecosystems* (pp. 527–567). New York, NY: Marcel Dekker.

Jayas, D. S., Alagusundaram, K., Shunmugam, G., Muir, W. E., & White, N. D. G. (1994). Simulated temperatures of stored grain bulks. *Canadian Agricultural Engineering, 36*(4), 239–245.

Jayas, D. S., White, N. D. G., & Muir, W. E. (Eds.). (1995). *Stored-grain ecosystems* (p. 757). New York, NY: Marcel Dekker.

MDA (1987). Grain aeration and unheated air drying. Publication No. Agdex 732-1. Manitoba Department of Agriculture, Winnipeg, MB.

Ominski, K. H., Marquardt, R. R., Sinha, R. N., & Abramson, D. (1994). Ecological aspects of growth and mycotoxin production by storage fungi. In J. D. Miller, & H. L. Trenholm (Eds.), *Mycotoxins in grain* (pp. 287–312). St Paul, MN: Eagan Press.

Pabis, S., Jayas, D. S., & Cenkowski, S. (1998). *Grain drying: Theory and practice*. New York, NY: John Wiley, 303 p.

Prasad, D. C., Muir, W. E., & Wallace, H. A. H. (1978). Characteristics of freshly harvested wheat and rapeseed. *Transactions of the American Society of Agricultural Engineers, 21*, 782–784.

Sinha, R. N. (1973a). Interrelations of physical, chemical, and biological variables in the deterioration of stored grains. In R. N. Sinha, & W. E. Muir (Eds.), *Grain storage: Part of a system* (pp. 15–47). Westport, CT: AVI Pub. Co., Inc.

Sinha, R. N. (1973b). Ecology of storage. *Annals de Technologie Agricole, 22*, 351–369.

Sinha, R. N., Mills, J. T., Wallace, H. A. H., & Muir, W. E. (1981). Quality assessment of rapeseed stored in ventilated and non-ventilated farm bins. *Sciences des Aliments, 1*, 247–263.

Sinha, R. N., & Watters, F. L. (1985). Insect pests of flour mills, grain elevators, and feed mills and their control. Publication 1776. Research Branch, Agriculture Canada, Ottawa, Ont. 290 p.

Sinha, R. N., Yaciuk, G., & Muir, W. E. (1973). Climate in relation to deterioration of stored grain. A multivariate study. *Oecologia, 12*, 69–88.

Tipples, K. H. (1995). Quality and nutritional changes in stored grain. In D. S. Jayas, N. D. G. White, & W. E. Muir (Eds.), *Stored-grain ecosystems* (pp. 325–351). New York, NY: Marcel Dekker, 757 p.

White, N. D. G. (1995). Insects, mites, and insecticides in stored-grain ecosystems. In D. S. Jayas, N. D. G. White, & W. E. Muir (Eds.), *Stored-grain ecosystems* (pp. 123–167). New York, NY: Marcel Dekker.

White, N. D. G. (Ed.). (2000). Protection of farm-stored grains, oilseeds, and pulses from insects, mites and molds. Cereal Research Centre, Agriculture and Agri-Food Canada, http://res2.agr.ca/winnipeg/cgs_e.htm.

White, N. D. G., & Sinha, R. N. (1980). Changes in stored-wheat ecosystems infested with two combinations of insect species. *Canadian Journal of Zoology, 58*, 1524–1534.

White, N. D. G., Demianyk, C. J., Sinha, R. N., Mills, J. T., Abramson, D., Muir, W. E., & Jayas, D. S. (1999). Multi-year monitoring for quality changes of grain stored in 550 tonne capacity grain bins in western Canada. *Proceedings of the 7th international working conference on stored-product protection: Vol. 2* (pp. 1301–1313). Chengdu, PR China: Sichuan Publishing House of Science and Technology.

Wilson, D. M., & Abramson, D. (1992). Mycotoxins. In D. B. Sauer (Ed.), *Storage of cereal grains and their products* (pp. 341–391). St Paul, MN: American Association of Cereal Chemists.